ADA046369

# AVIATION RESEARCH LABORATORY

## INSTITUTE OF AVIATION
### UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TECHNICAL REPORT

**VAL ARL**

# THE ISOLATION OF MINIMUM SETS OF VISUAL IMAGE CUES SUFFICIENT FOR SPATIAL ORIENTATION DURING AIRCRAFT LANDING APPROACHES

Janice E. Eisele, Robert C. Williges, Stanley N. Roscoe

ARL-76-16/ONR-76-3
NOVEMBER 1976

DDC
RECEIVED
NOV 4 1977
B

# Best
# Available
# Copy

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER <br> ARL-76-16/ONR-76-3 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE *(and Subtitle)* <br> THE ISOLATION OF MINIMUM SETS OF VISUAL IMAGE CUES SUFFICIENT FOR SPATIAL ORIENTATION DURING AIRCRAFT LANDING APPROACHES. | | 5. TYPE OF REPORT & PERIOD COVERED <br> Technical Report, 1974-76 <br> 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s) <br> Janice E. Eisele, Robert C. Williges and Stanley N. Roscoe | | 8. CONTRACT OR GRANT NUMBER(s) <br> N00014-76-C-0081 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS <br> Aviation Research Laboratory <br> Institute of Aviation <br> University of Illinois, Savoy, IL 61874 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS <br> NR 196-133 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS <br> Office of Naval Research (Code 455) <br> 800 North Quincy Street <br> Arlington, Virginia 22217 | | 12. REPORT DATE <br> November 1976 <br> 13. NUMBER OF PAGES <br> 36 |
| 14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) | | 15. SECURITY CLASS. *(of this report)* <br> Unclassified <br> 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

| | | |
|---|---|---|
| Flight Displays | Contact Analog Displays | Central Composite Designs |
| Display Symbology | Flight Control | Regression Analysis |
| Human Factors | Cockpit Workload | Visual Orientation |
| Attitude Displays | Computer-Generated Displays | |
| Cockpit Instrumentation | Aviation Psychology | |

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An experimental investigation of synthetic imaging displays was directed toward the isolation of minimum sets of visual cues sufficient for spatial orientation in ground-referenced aircraft landing approaches. Thirty-two flight instructors viewed static computer-generated airport scenes TV-projected onto a large screen viewed from the cockpit of a twin-engine general aviation trainer. Judgments of lateral and vertical deviations from a four-degree approach to landing aim point in the display were made to 32 combinations of

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73

20. four contact analog cues: runway outline, runway touchdown zone, runway centerline, and ground plane texture; and one guidance cue: glidepath-localizer symbol. Each resulting display was responded to once or more from each of 27 different flight position and attitude viewpoints by each of eight subjects in different serial orders. Dependent measures were response choice and response latency. The most accurate glidepath and course deviation judgments were made when the guidance cue glidepath was in the set. When only contact analog cues were present the best judgments of spatial orientation consistently were made when the runway outline was present at far and medium ranges from touchdown and when the runway centerline was present at near range. ←—

AVIATION RESEARCH LABORATORY


University of Illinois at Urbana-Champaign
Willard Airport
Savoy, Illinois
61874


Technical Report

ARL-76-16/ONR-76-3

November 1976


THE ISOLATION OF MINIMUM SETS OF VISUAL IMAGE CUES
SUFFICIENT FOR SPATIAL ORIENTATION DURING AIRCRAFT LANDING APPROACHES

Janice E. Eisele, Robert C. Williges, and Stanley N. Roscoe

ACKNOWLEDGMENT

CONTEXT

The Aviation Research Laboratory of the University of Illinois has investigated integrated synthetic-imaging displays and computer-augmented flight control for the Office of Naval Research. Mr. Gerald Malecki, Assistant Director, Engineering Psychology Programs, was the technical monitor of the research. Professor Stanley N. Roscoe was the principal investigator during the initial phase of study and experimental apparatus development; Professor Robert C. Williges served as principal investigator while Professor Roscoe was on academic leave during 1975-76.

The research was directed toward (1) the isolation of minimum sets of visual image cues sufficient for spatial and geographic orientation in the various ground-referenced phases of representative flight missions, (2) the generation and spatially integrated presentation of computed guidance commands and fast-time flight path predictors, and (3) the matching of the dynamic temporal relationships among these display indications for compatibility with computer-augmented flight performance control dynamics, both within each ground-referenced mission phase and during transitions between phases. The investigative program drew selectively upon past work done principally under ONR sponsorship or partial sponsorship, including the ANIP and JANAIR programs.

To study experimentally the effectiveness of alternate sets of
visual cues the Aviation Research Laboratory developed a highly versa-
tile computer-generated display system to present dynamic pictorial
images either on a head-down, panel-mounted CRT or on a head-up tele-
vision projection to a large screen mounted in front of the pilot's
windshield on the Link GAT-2 simulator. Due to the great flexibility
of the pictorial display, visual cues and flight status information
could be manipulated experimentally. The experiment reported herein was
conducted to isolate the visual cues sufficient for approach and landing
by measuring subjects' orientation responses to TV-projections of static
computer-generated images containing various combinations of skeletal
symbology from various positions and attitudes on final approaches to
landings.

TABLE OF CONTENTS

LIST OF TABLES

## LIST OF FIGURES

## BACKGROUND

Aircraft technology has advanced rapidly since its beginning at the turn of the century, yet only recently has there been widespread recognition by the aviation community of the constantly changing role of the pilot in aircraft operations. Innovations in display technology, made possible by the advent of advanced airborne digital computers, can improve the pilot's performance by processing information to minimize transformations, including integrations and differentiations as well as simple arithmetic computations, required in the decision making and flight control process. In this way, computers can help pilots perform their new duties better.

In making and carrying out flight decisions, a pilot must convert long-term mission objectives to subgoals for each flight instrument, relate instrument subgoals to each other and control inputs to aircraft responses and instrument indications. For each of these functions, computers can improve pilot performance by storing, transforming, and integrating sensed information. With the ever increasing air traffic densities, expanding requirements for all-weather, night, and nap-of-the-earth operations, and the burgeoning complexity of navigation and weapon delivery profiles, the application of airborne computers to control augmentation and display integration is no longer generally discounted as a radical, irresponsible, dangerously unreliable folly.

## Pictorial Vertical Situation Displays

To apply computers effectively to the transformation of sensed
information and the generation of synthetic displays, information that
is closely related functionally should be presented in a common frame
of reference. More specifically, information concerning an airplane's
attitude and flight path relative to surface objects, such as ground
targets, airport runways, or carrier decks, should be presented in a
pictorial, forward-looking, vertical situation display (VSD) context.
All pictorial displays, by Carel's (1965) definition, have two common
characteristics: first, the elements in the display are geometrically
similar to those in the contact world; and second, the motion of displayed
elements is analagous to that of their real-world correlates.

Literal VSDs. The most literal VSDs for approach and landing are
flight periscopes and forward-looking IR and TV displays. Roscoe,
Hasler, and Doughtery (1966) conducted several studies using a projection
periscope mounted in a Cessna T-50. The pilot saw the forward view on
an 8-inch screen mounted above the instrument panel with the periscope
projecting through an aluminum windshield. Although safe takeoffs and
landings were made by reference to this projected forward view, the
accuracy of landings in terms of constant and variable errors was
reliably influenced by image magnification, the optimum value being
about 1.25. Campbell, McEachern, and Marg (1955) used a binocular
periscope to investigate approach and landing performance and reached
similar conclusions as to image magnification.

Kibort and Drinkwater (1964) tested the effectiveness of a TV display in a DC-3 aircraft for the final approach and landing. A steerable camera was mounted on the nose and a second camera was placed just forward of the tailwheel. The output of either could be fed to a 14-inch monitor that subtended 16-17 degrees at the pilot's eye. The task of the pilot was to fly landing approaches from three miles out through touchdown and rollout. Kibort and Drinkwater concluded that only quantitative airspeed, vertical speed, and altitude information was necessary when flying the TV display.

From the evidence available, an unaided literal TV display appears inadequate for use as the primary instrument for approach and landing. The addition of quantitative information on flight and navigation guidance parameters would improve the pilot's spatial and geographical orientation cues. Information presented by a literal pictorial display is believable due to the availability of all the real-world landmarks, and this allows the pilot to decide among alternative courses of action with high confidence. In this way, literal displays take advantage of the overlearned perceptual habits that pilots acquire from VFR flight.

Analog VSDs. In the late 1950s through early 1960s, the ANIP program (Army-Navy Instrumentation Program) followed by the JANAIR (Joint Army Navy Aircraft Instrumentation Research) program were conducted. These programs included investigations and development of advanced instrument systems for aircraft and standards for electronic and optically-generated aircraft displays.

Carel (1965), in his frequently cited JANAIR report, defined a contact analog display as "the point perspective projection of a three-dimensional model to a picture plane." Typical computer-generated models contain reference objects significant for flight performance, such as a surface representing the horizon and ground plane, a surface representing the command path for the pilot to follow, and other surfaces or objects useful during various phases of a mission. Most importantly, the displayed surface dynamics are similar to those of their analog surfaces in the natural visual environment. The displayed surfaces still follow the laws of motion perspective, thus providing information coded in a fashion analogous to the coding provided in visual contact flight.

Investigators at Bell Helicopter Company carried out simulator and flight tests using a contact analog display developed by Norden. Abbott and Dougherty (1964) studied the accuracy with which altitude and ground-speed could be interpreted using the Norden display. No control was required of the subject pilots in the open-loop task. It was concluded that the display offered the same problem areas as does VFR flight in the presentation of altitude and groundspeed information. The higher the altitude or speed, the poorer was the judgment, and an interaction existed between speed and altitude judgments, with increasing difficulty in interpreting either as the other increased.

Emery and Dougherty (1964) studied low-altitude, ground-referenced maneuvers in the Bell moving-base helicopter simulator. The content of the displays was varied in four test conditions: ground plane only, ground plane and landing pad; ground plane with flight path border; and

ground plane, flight path border, and "tarstrips" perpendicular to the border edges. Pilot performance improved as command guidance information was added in the form of a desired flight path.

In a third investigation, Dougherty, Emery, and Curtin (1964) compared pilot performances when flying with standard instruments and with the contact analog display. Two groups were trained to a criterion of "performance equivalence" with the two types of display in the moving-base helicopter simulator. Subjects were required to control altitude, heading, course, and airspeed while concurrently performing a digit-reading side task at variable rates. Pilot performances with the two types of display did not differ reliably under the control condition (no digit-reading task) or under the slowest rate condition; however, as the side-task rate was increased progressively, performance on the contact analog display remained relatively stable, while performance on the standard instruments deteriorated.

The authors concluded that "the pictorial JANAIR display was by far the superior display as the visual workload increased," and attributed this to three factors:

1. The pilot may more quickly assimilate qualitative information from the pictorial display.

2. Using conventional information, the pilot samples one parameter of information per glance. With the pictorial display, he accumulates information on more than one parameter per glance.

3. Because of its relatively large angular field of view, the pictorial display permits use of peripheral vision.

Williams and Kronholm (1965) reported the results from simulation studies of an integrated electronic vertical situation display developed by Norden under JANAIR support. The object of the Universal Contact Analog Display (UCAD) research program was to formulate a methodology for determining VSD requirements and to generate design criteria for an integrated cockpit display applicable to both fixed-wing and rotary-wing aircraft. Significant among the conclusions and recommendations were: 1) the desirability of quantitative indications of altitude, airspeed, vertical velocity, turn rate; and 2) the desirability of incorporating computed control information into the display for critical tasks.

Ketchel and Jenny (1968) surveyed the literature, presented display design considerations, and delineated areas in which further research was needed. Their report included consideration of information requirements, symbology and format, and quantitative display characteristics, with the primary emphasis on CRT display for fixed-wing aircraft. Following publication of the Ketchel and Jenny report, a new program of experimentation on contact analog displays was undertaken at the Naval Missile Center, Pt. Mugu.

Cross and Cavellero (1971) investigated pilot performance during simulated landing approaches to an aircraft carrier. Performances in the simulator were found to be "comparable" to performances on approaches to a CVA carrier in an actual F-4 aircraft. In addition, pilots expressed the opinion that the nature and level of task difficulty experienced in the simulator were similar to those encountered in the aircraft in the landing phase. From the evidence, synthetically generated contact analog

displays appeared to facilitate spatial orientation and allow manual control not greatly different from literal imaging displays of comparable dimensions.

A projected flight path indication was added to the display used by Cross and Cavallero to allow investigation of a possible means of further improving performance during approach and landing. Wulfeck, Prosin, and Burger (1973) had pilots fly approaches in a fixed-base F-4 simulator with the baseline contact analog display, the predictor display, and a glideslope reference element of the predictor display. The predictor display proved reliably superior to the baseline display in all comparisons, including altitude and lateral error variability, oscillatory control patterns, landings within error criteria, and "acceptable" approaches at the ramp.

## Unanswered Questions

Although much has been learned from the experiments just reviewed, the overriding conclusion is that pilots can land airplanes by reference to an infinite number of sets of visual cues, each of which may be sufficient to support performance at a particular level, no one of which is uniquely necessary. Thus, when one speaks of the "essential" visual cues for landing, he is implicitly addressing the unanswered questions concerning the relative effectiveness of the various sets of cues that might be presented by a visual display within our present sensing, computing, and display technology.

The approach taken in the present experimental investigation was to select a clearly sufficient set of visual indications symbolic

of geometric aspects of the contact visual scene and to conduct a
parametric comparison of their various combinations in terms of the
performances of qualified pilots in judging their flight positions and
attitudes relative to the nominally correct landing approach path.
Open-loop responses were made to successive static presentations of
flight situations represented by computer-generated images of the
various display configurations projected onto a large screen viewed
from the cockpit of a flight simulator.

METHOD

## Apparatus

A Raytheon 704 digital computer was used to generate the displays,
control the experimental display presentations, collect the dependent
measures, and record the data. The computer-generated displays were
imaged on a CRT from which a TV camera relayed them to an Advent Video-
beam projector. The Advent projector, mounted above the simulator cab,
projected the TV image onto a 68.5 x 51.5-in spherical-section screen
mounted in front of the simulator, a modified Singer-Link General Aviation
Trainer (GAT-2). The left half of the windscreen was removed so that the
subject, sitting in the pilot's seat, had an unobstructed view, straight
ahead, of the Advent screen. The simulator's cab and Advent system as
shown in Figure 1 were entirely enclosed in a black plastic curtain that
shielded the projection screen from ambient light. The response device
was a nine-button keyboard, installed on the end of the subject's right
armrest and adjustable for various arm and finger lengths.

## Experimental Design

The displays were developed by the full factorial combination of
five symbolic elements, four representative of visible aspects of an
airport scene and one synthetic element not present in the real world.
The real-world or "contact analog" display elements included:
(1) runway outline, (2) touchdown zone, (3) runway centerline, and
(4) a grid of "section lines" that served to define a textured surface.
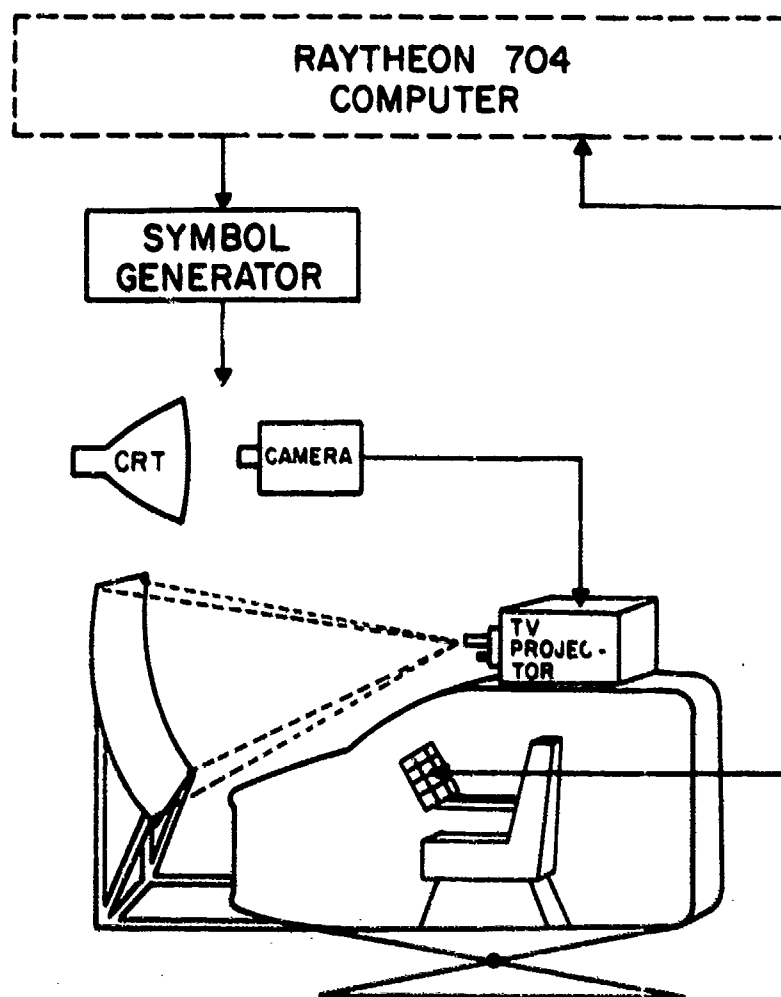
**Figure 1.** Pictorial landing display simulation equipment.

The synthetic element was a row of four "T-bars" of increasing height positioned along the approach centerline at 1/4, 1/2, 1, and 2 miles from the touchdown aimpoint to provide a visual representation of an imaginary glideslope and localizer path (analogous to a "highway in the sky").

Two additional elements from the contact scene, present in all 32 displays, were touchdown aimpoint and horizon. To approximate the viewing condition that would result in subjective equality of distance judgments relative to those obtained with a direct, contact view of a real airport, the computer-generated scenes were projected with a magnification factor of 1.2 as measured at the pilot's eye position (Roscoe, Hasler, and Dougherty, 1966). The 32 displays were divided into four groups of eight displays each by selecting two elements, runway outline and glideslope-localizer path, as between-subjects factors. The four groups of displays are given in Table 1 and in Figures 2-5.

A central-composite design (CCD) was used to derive 27 different viewpoints from which subjects would respond to the airport scenes projected onto the screen mounted in front of the simulator. This systematic strategy provided an economical sampling of ranges from touchdown aimpoint, vertical and lateral deviation from the glideslope/localizer T-bars, and aircraft pitch and bank attitudes. The coded factor levels and corresponding real-world values used to generate the 27 different perspective views of the landing approach scene (for each of the 32 displays) are shown in Table 2. A one-half replicate of a $2^5$ factorial combination of variables (±1 values), plus 2 x 5 extended axial "star" points (±a values), plus 10 replications of the centerpoint (0 values) yielded 36 presentations

TABLE 1

Visual Elements Present or Absent in Each of the Eight Displays in Each of the Four Display Groups Presented to Independent Groups of Eight Flight Instructors Each

| Group I | | | | | Group II | | | | | Group III | | | | | Group IV | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Runway Outline | Touchdown Zone | Runway Centerline | Texture Grid | Glideslope/Localizer | Runway Outline | Touchdown Zone | Runway Centerline | Texture Grid | Glideslope/Localizer | Runway Outline | Touchdown Zone | Runway Centerline | Texture Grid | Glideslope/Localizer | Runway Outline | Touchdown Zone | Runway Centerline | Texture Grid | Glideslope/Localizer |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 |
| 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Legend:

0 = without element;  1 = with element

All displays with aimpoint and visible horizon.
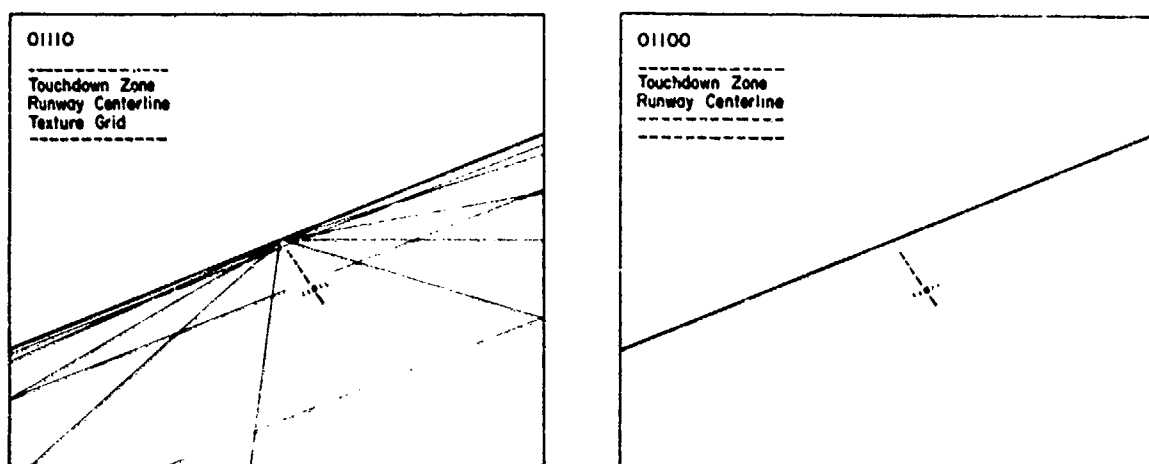
**Figure 2.** Group I display elements: composite of all Group I elements (left) and composite of Group I elements with Texture Grid omitted (right).
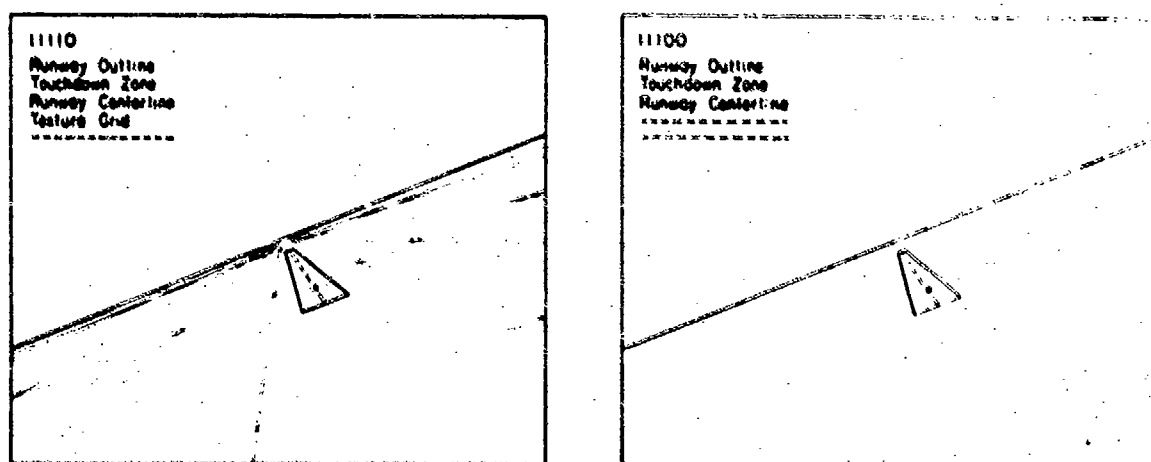


**Figure 3.** Group II display elements: composite of all Group II elements (left) and composite of Group II elements with Texture Grid omitted (right).
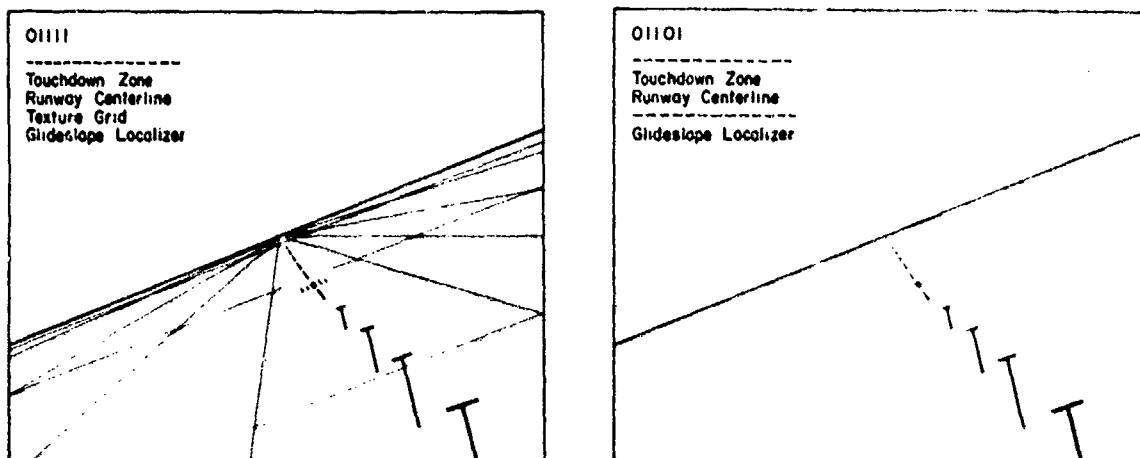
Figure 4.  Group III display elements:  composite of all Group III elements (left) and composite of Group III elements with Texture Grid omitted (right).
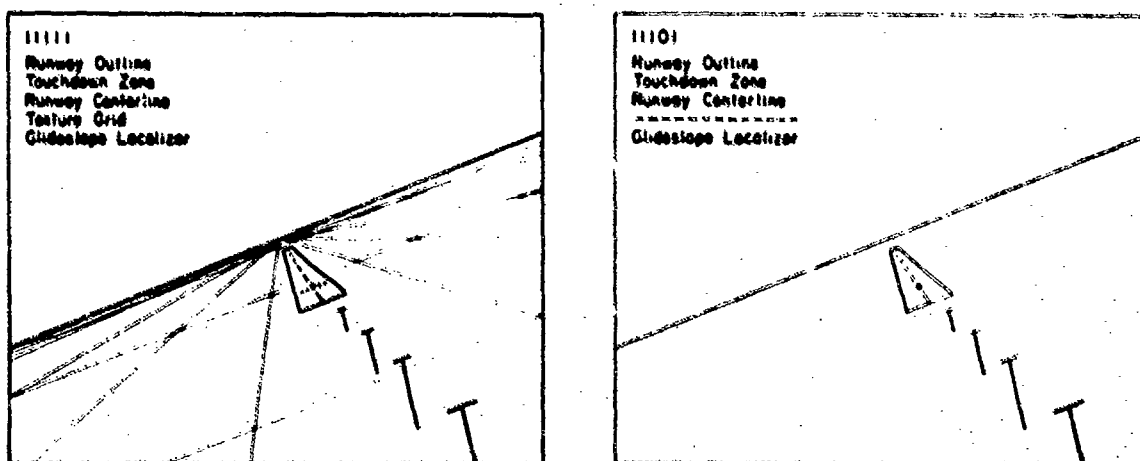


Figure 5.  Group IV display elements:  composite of all Group IV elements (left) and composite of Group IV elements with Texture Grid omitted (right).

TABLE 2

Coded and Real-World Values of the Flight Position and Attitude Variables
in Accordance with the Central Composite Experimental Design

| | Coded Values | | | | |
|---|---|---|---|---|---|
| | $-\alpha$ | $-1$ | $0$ | $+1$ | $+\alpha$ |
| Position Variables | Real-World Values | | | | |
| RANGE (feet from aimpoint) | 1000 | 2730 | 4460 | 6190 | 7920 |
| VERTICAL DEVIATION (degrees from glideslope) | -1.0 | -0.5 | 0 | 0.5 | 1.0 |
| LATERAL DEVIATION (degrees from localizer) | -1.0 | -0.5 | 0 | 0.5 | 1.0 |
| Attitude Variables | | | | | |
| PITCH (degrees from horizontal) | 0 | -2 | -4 | -6 | -8 |
| BANK (degrees from horizontal) | -10 | -5 | 0 | 5 | 10 |

of each display (Cochran and Cox, 1957). The value of $\alpha$ was set at 2 to make the design rotatable (Myers, 1971; Williges, 1976).

Subjects were randomly assigned to one of the four display groups, and within a group each of the eight subjects saw the eight displays in a different order in accordance with a counterbalanced design. The counterbalancing of the presentation orders caused each display to appear once in each serial position and to precede and follow every other display once across each group of eight subjects. The 36 viewpoints from which subjects responded to any one display were randomized, with the constraint that no display was presented to more than one subject in the same viewpoint order throughout the experiment.

## Subjects

Thirty-two University of Illinois flight instructors volunteered to participate. Thirty males and two females between the ages of 20 and 45 each had at least 5 hours of flight time during the six months preceding their participation in the experiment.

## Experimental Procedure

A subject began by reading a short introduction to the experiment and an explanation of his task. He was given a written explanation of the visual-world cues he would see according to his group assignment. All questions were answered before the next phase of the task began. The subject was then seated in the left seat of the simulator, and the arm-rest keyboard was adjusted if necessary. The keyboard and its use were explained to the subject, and any questions he had were answered.

When a subject had no further questions, he was given a series of
16 practice trials identical to the subsequent test trials. A square
appeared on the display screen, signalling that the computer was ready
for the trial. When the subject was ready, he pressed and released the
home-base key. Immediately, a display appeared on the screen. The
subject would then make a response indicating his vertical and lateral
deviation relative to a 4-degree glideslope and localizer path by
pressing the appropriate key on the keyboard. During the practice trials,
the cues in the display were pointed out, and the appropriate responses
were discussed. Practice trials consisted of both "right on" approaches
with no deviation from the desired approach path and ones with vertical
and lateral deviations from the desired path, all viewed from various
flight attitudes.

After appearing for 15 sec, the display disappeared whether or not
the subject had responded. When the computer finished recording the data
for the trial and generating the next display, the box reappeared on the
screen indicating that the next trial could begin. The subject again
pressed the home-base key when ready. In this manner the subject had
control over the pacing of the session. After the practice trials,
questions were answered, and the test trials began. The 16 practice and
288 test trials required about 80 minutes. After the session the subject
was given a short questionnaire, any questions he had about the experi-
ment were answered, and he was thanked for his participation.

RESULTS

Table 3 presents the Percent Correct Responses and Median Latencies of all responses, both correct and incorrect, for each of the 32 displays at Far, Medium, and Near ranges from the runway aimpoint. "Far" and "Near" ranges from aimpoint include, respectively, the +1 and +α ranges and the -1 and -α ranges called for by the central-composite design, whereas the Medium range is the 0, or centerpoint, range called for by the design. The analyses of variance of these data are summarized in Tables 4-9.

In addition to these overall response data, the latencies of correct responses only were tabulated and analyzed, as were the incorrect responses and their associated latencies in the lateral and vertical dimensions separately. Although these detailed breakdowns are not presented, the multiple regression equations based thereon are given in Table 10. All statistical analyses of response latencies were performed on the logarithmic transformations of the raw data, thereby more closely satisfying the assumptions of normality of distributions and homogeneity of variances implicit in the application of parametric statistical treatments (Muller, 1949; Edwards, 1950).

Both an analysis of variance and a multiple regression analysis were performed on each set of data. Because the experimental variables were all dichotomous (each of the five display elements was either present or absent), the regression equations and the analyses of variance are merely alternate ways of expressing the same basic information. Of primary interest was the effect of each of the 32 visual element combinations on performance, both singly and in combination with the various other elements. Tables 4-9 show the main effects of the five display elements and their statistically reliable first-order interactions.

TABLE 3

Percent Correct Responses and Median Latencies of All Responses to Each of the 32 Displays at Far, Medium, and Near Ranges from the Touchdown Zone

| | DISPLAY | | | | RANGE TO TOUCHDOWN | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Far | | Medium | | Near | |
| Outline | TD Zone | Centerline | Texture | Glideslope | Percent Correct | Median Latency | Percent Correct | Median Latency | Percent Correct | Median Latency |
| 0 | 0 | 0 | 0 | 0 | 31.9 | 3.52 | 56.9 | 3.10 | 45.8 | 3.81 |
| 0 | 1 | 0 | 0 | 0 | 25.0 | 3.33 | 66.7 | 3.13 | 55.6 | 3.55 |
| 0 | 0 | 1 | 0 | 0 | 58.3 | 3.16 | 51.4 | 3.05 | 84.7 | 2.79 |
| 0 | 0 | 0 | 1 | 0 | 48.6 | 3.58 | 55.6 | 2.96 | 57.0 | 3.30 |
| 0 | 1 | 1 | 0 | 0 | 55.6 | 3.27 | 63.9 | 2.85 | 80.6 | 2.71 |
| 0 | 1 | 0 | 1 | 0 | 44.5 | 3.90 | 54.2 | 3.40 | 57.0 | 4.10 |
| 0 | 0 | 1 | 1 | 0 | 62.5 | 4.03 | 61.1 | 3.69 | 83.3 | 3.43 |
| 0 | 1 | 1 | 1 | 0 | 44.5 | 4.22 | 51.4 | 3.85 | 81.9 | 3.43 |
| 1 | 0 | 0 | 0 | 0 | 59.7 | 2.72 | 70.8 | 2.54 | 65.3 | 2.63 |
| 1 | 1 | 0 | 0 | 0 | 59.7 | 3.01 | 73.6 | 3.02 | 75.0 | 2.94 |
| 1 | 0 | 1 | 0 | 0 | 61.1 | 3.50 | 75.0 | 3.02 | 61.1 | 3.75 |
| 1 | 0 | 0 | 1 | 0 | 63.1 | 3.20 | 62.5 | 3.09 | 58.3 | 3.08 |
| 1 | 1 | 1 | 0 | 0 | 63.9 | 3.13 | 68.1 | 3.30 | 73.6 | 3.16 |
| 1 | 1 | 0 | 1 | 0 | 75.0 | 3.64 | 68.1 | 3.92 | 61.1 | 3.34 |
| 1 | 0 | 1 | 1 | 0 | 75.0 | 3.45 | 61.1 | 3.20 | 59.7 | 2.88 |
| 1 | 1 | 1 | 1 | 0 | 75.0 | 2.93 | 61.1 | 3.18 | 62.5 | 2.85 |
| 0 | 0 | 0 | 0 | 1 | 98.6 | 1.60 | 91.7 | 1.44 | 90.1 | 1.93 |
| 0 | 1 | 0 | 0 | 1 | 97.2 | 1.57 | 91.7 | 1.70 | 87.5 | 1.92 |
| 0 | 0 | 1 | 0 | 1 | 98.6 | 1.78 | 94.5 | 1.73 | 90.3 | 2.11 |
| 0 | 0 | 0 | 1 | 1 | 98.6 | 1.70 | 93.1 | 1.83 | 91.7 | 2.18 |
| 0 | 1 | 1 | 0 | 1 | 100.0 | 1.67 | 94.5 | 1.79 | 95.8 | 1.76 |
| 0 | 1 | 0 | 1 | 1 | 98.6 | 1.79 | 93.1 | 2.43 | 93.1 | 2.06 |
| 0 | 0 | 1 | 1 | 1 | 94.5 | 1.67 | 97.2 | 2.04 | 93.1 | 2.04 |
| 0 | 1 | 1 | 1 | 1 | 95.8 | 1.72 | 98.6 | 1.85 | 98.6 | 1.92 |
| 1 | 0 | 0 | 0 | 1 | 98.6 | 1.95 | 94.5 | 1.98 | 97.2 | 1.82 |
| 1 | 1 | 0 | 0 | 1 | 98.6 | 1.88 | 98.6 | 1.87 | 94.5 | 1.74 |
| 1 | 0 | 1 | 0 | 1 | 98.6 | 1.64 | 97.2 | 1.84 | 100.0 | 1.36 |
| 1 | 0 | 0 | 1 | 1 | 98.6 | 1.74 | 97.2 | 1.70 | 97.2 | 1.73 |
| 1 | 1 | 1 | 0 | 1 | 100.0 | 1.57 | 91.7 | 1.88 | 95.8 | 1.68 |
| 1 | 1 | 0 | 1 | 1 | 100.0 | 1.68 | 93.1 | 1.95 | 97.2 | 1.77 |
| 1 | 0 | 1 | 1 | 1 | 98.6 | 1.67 | 95.8 | 1.73 | 97.2 | 1.62 |
| 1 | 1 | 1 | 1 | 1 | 94.5 | 1.74 | 94.5 | 1.78 | 91.1 | 1.77 |

TABLE 4

Summary of Analysis of Variance and Results for Percent Correct Responses at Far Range

| Source of Variance | F | df | p |
|---|---|---|---|
| Runway Outline | 7.856 | 1,28 | .009 |
| Touchdown Zone | 1.059 | 1,28 | .312 |
| Runway Centerline | 4.998 | 1,28 | .034 |
| Texture Grid | 1.300 | 1,28 | .264 |
| Glideslope/Localizer | 115.759 | 1,28 | .000 |

Reliable Interactions

| | | | |
|---|---|---|---|
| Outline x Glideslope | 6.876 | 1,28 | .014 |
| Centerline x Glideslope | 7.466 | 1,28 | .011 |

Cell Means and Effects

Outline
0 = 72.1        Presence of Runway Outline (1) resulted in a reliably
1 = 82.8        higher percentage of correct responses.

Touchdown Zone
0 = 78.1        Percentages for absence (0) and presence (1) of
1 = 76.7        Touchdown Zone did not differ reliably.

Centerline
0 = 75.1        Presence of Runway Centerline (1) resulted in a
1 = 79.8        reliably higher percentage of correct responses.

Texture
0 = 75.4        Percentages for absence (0) and presence (1) of
1 = 79.5        Texture Grid did not differ reliably.

Glideslope
0 = 56.8        Presence of Glideslope/Localizer T-bars (1) resulted
1 = 98.1        in a reliably higher percentage of correct responses.

Outline x Glideslope
0/0 = 46.4   0/1 = 97.7   Presence of the Runway Outline had no evident effect
1/0 = 68.0   1/1 = 98.4   when the Glideslope/Localizer was present (0/1 and 1/1),
                          but its presence yielded a higher percentage of correct
                          responses when the Glideslope/Localizer was absent
                          (1/0 versus 0/0).

Centerline x Glideslope
0/0 = 51.6   0/1 = 98.6   Presence of the Runway Centerline interacted with the
1/0 = 62.0   1/1 = 97.6   absence of the Glideslope/Localizer in the same way
                          that the Runway Outline did.

TABLE 5

Summary of Analysis of Variance and Results for Percent Correct Responses at
Medium Range

| Source of Variance | $F$ | $df$ | $p$ |
|---|---|---|---|
| Runway Outline | 1.658 | 1,28 | .208 |
| Touchdown Zone | 0.157 | 1,28 | .312 |
| Runway Centerline | 0.039 | 1,28 | .845 |
| Texture Grid | 1.439 | 1,28 | .240 |
| Glideslope/Localizer | 57.491 | 1,28 | .000 |

(No first-order interaction was statistically reliable.)

Cell Means and Effects

Outline
0 = 76.0          Percentages for absence (0) and presence (1) of
1 = 81.4          Runway Outline did not differ reliably. *

Touchdown Zone
0 = 78.5          Percentages for absence (0) and presence (1) of
1 = 78.9          Touchdown Zone did not differ reliably.

Centerline
0 = 78.8          Percentages for absence (0) and presence (1) of
1 = 78.6          Runway Centerline did not differ reliably.

Texture
0 = 80.0          Percentages for absence (0) and presence (1) of
1 = 77.3          Texture Grid did not differ reliably.

Glideslope
0 = 62.6          Presence of Glideslope/Localizer T-bars (1) resulted
1 = 94.8          in a reliably higher percentage of correct responses.

---

* The corresponding regression analysis (see Table 10), which took into
account all of the individual response data for the ten replications of
the centerpoint of the central composite experimental design, showed the
presence of the Runway Outline to contribute reliably to correct responses
at Medium Range ($p < .05$). The analysis of variance included only the first
of the ten centerpoint responses by each subject.

TABLE 6                                                                          22

Summary of Analysis of Variance and Results for Percent Correct Responses at
Near Range

| Source of Variance | F | df | p |
|---|---|---|---|
| Runway Outline | 0.002 | 1,28 | .970 |
| Touchdown Zone | 1.258 | 1,28 | .272 |
| Runway Centerline | 21.958 | 1,28 | .000 |
| Texture Grid | 0.073 | 1,28 | .790 |
| Glideslope/Localizer | 39.037 | 1,28 | .000 |

Reliable Interactions

| | | | |
|---|---|---|---|
| Outline x Centerline | 23.910 | 1,28 | .000 |
| Centerline x Glideslope | 12.712 | 1,28 | .001 |

Cell Means and Effects

Outline
0 = 80.4          Percentages for absence (0) and presence (1) of
1 = 80.6          Runway Outline did not differ reliably.

Touchdown Zone
0 = 79.5          Percentages for absence (0) and presence (1) of
1 = 81.4          Touchdown Zone did not differ reliably.

Centerline
0 = 76.5          Presence of Runway Centerline (1) resulted in a
1 = 84.5          reliably higher percentage of correct responses.

Texture
0 = 80.8          Percentages for absence (0) and presence (1) of
1 = 80.1          Texture Grid did not differ reliably.

Glideslope
0 = 66.4          Presence of Glideslope/Localizer T-bars (1) resulted
1 = 94.5          in a reliably higher percentage of correct responses.

Outline x Centerline
0/0 = 72.2  0/1 = 88.5   Presence of Runway Centerline in the absence of a
1/0 = 80.7  1/1 = 80.4   Runway Outline (0/1) resulted in a disproportion-
                         ately high percentage of correct responses.

Centerline x Glideslope
0/0 = 59.4  0/1 = 93.6   Although the highest percentage of correct responses
1/0 = 73.4  1/1 = 95.5   occurred when both Glideslope/Localizer and Runway
                         Centerline were present (1/1), the percentage was
                         disproportionately high when either was present in
                         the absence of the other (1/0 or 0/1), and the
                         percentage with Glideslope/Localizer present in the
                         absence of Runway Centerline (0/1) was nearly equal
                         to that with both present.

TABLE 7

Summary of Analysis of Variance and Results for Median Latencies of All
Responses at Far Range

| Source of Variance | F | df | p |
|---|---|---|---|
| Runway Outline | 0.124 | 1,28 | .728 |
| Touchdown Zone | 0.000 | 1,28 | .988 |
| Runway Centerline | 0.007 | 1,28 | .936 |
| Texture Grid | 3.232 | 1,28 | .083 |
| Glideslope/Localizer | 23.496 | 1,28 | .000 |

(No first-order interaction was statistically reliable.)

Cell Means and Effects

Outline
0 = 2.47 sec          Latencies for absence (0) and presence (1) of
1 = 2.34              Runway Outline did not differ reliably.

Touchdown Zone
0 = 2.40             Latencies for absence (0) and presence (1) of
1 = 2.40             Touchdown Zone did not differ reliably.

Centerline
0 = 2.41             Latencies for absence (0) and presence (1) of
1 = 2.40             Runway Centerline did not differ reliably.

Texture
0 = 2.33             Latencies for absence (0) and presence (1) of
1 = 2.48             Texture Grid did not differ reliably.

Glideslope
0 = 3.39             Presence of Glideslope/Localizer T-bars (1) resulted
1 = 1.71             in reliably shorter response latencies.

TABLE 8

Summary of Analysis of Variance and Results for Median Latencies of All
Responses at Medium Range

| Sources of Variance | F | df | p |
|---|---|---|---|
| Runway Outline | 0.001 | 1,28 | .972 |
| Touchdown Zone | 3.118 | 1,28 | .088 |
| Runway Centerline | 0.673 | 1,28 | .419 |
| Texture Grid | 5.324 | 1,28 | .029 |
| Glideslope/Localizer | 12.459 | 1,28 | .001 |

Reliable Interaction

| Touchdown Zone x Centerline | 4.791 | 1,28 | .037 |
|---|---|---|---|

Cell Means and Effects

Outline
0 = 2.42 sec
1 = 2.40

Latencies for absence (0) and presence (1) of
Runway Outline did not differ reliably.

Touchdown Zone
0 = 2.33
1 = 2.48

Latencies for absence (0) and presence (1) of
Touchdown Zone did not differ reliably.

Centerline
0 = 2.38
1 = 2.44

Latencies for absence (0) and presence (1) of
Runway Centerline did not differ reliably.

Texture
0 = 2.30
1 = 2.52

Presence of Texture Grid (1) resulted in reliably
longer response latencies.

Glideslope
0 = 3.19
1 = 1.82

Presence of a Glideslope/Localizer T-bars (1)
resulted in reliably shorter response latencies.

Touchdown Zone x Centerline
0/0 = 2.24   0/1 = 2.43
1/0 = 2.53   1/1 = 2.44

Presence of Touchdown Zone marker in the absence of a
Runway Centerline (1/0) resulted in disproportionately
long response latencies, whereas its presence made no
reliable difference when the Runway Centerline was
present (0/1 versus 1/1).

TABLE 9                                                                    25

Summary of Analysis of Variance and Results for Median Latencies of All
Responses at Near Range

| Source of Variance | F | df | p |
|---|---|---|---|
| Runway Outline | 0.581 | 1,28 | .452 |
| Touchdown Zone | 0.168 | 1,28 | .685 |
| Runway Centerline | 1.542 | 1,28 | .225 |
| Texture Grid | 1.306 | 1,28 | .263 |
| Glideslope/Localizer | 14.087 | 1,28 | .001 |

Reliable Interactions

| | | | |
|---|---|---|---|
| Outline x Texture | 4.264 | 1,28 | .048 |
| Touchdown Zone x Texture | 4.742 | 1,28 | .038 |

Cell Means and Effects

Outline
0 = 2.58 sec        Latencies for absence (0) and presence (1) of Runway
1 = 2.31            Outline did not differ reliably.

Touchdown Zone
0 = 2.46            Latencies for absence (0) and presence (1) of
1 = 2.43            Touchdown Zone did not differ reliably.

Centerline
0 = 2.50            Latencies for absence (0) and presence (1) of Runway
1 = 2.39            Centerline did not differ reliably.

Texture
0 = 2.41            Latencies for absence (0) and presence (1) of Texture
1 = 2.48            Grid did not differ reliably.

Glideslope
0 = 3.21            Presence of Glideslope/Localizer T-bars (1) resulted
1 = 1.86            in reliably shorter response latencies.

Outline x Texture
0/0 = 2.49   0/1 = 2.70    Presence of the Texture Grid in the absence of a
1/0 = 2.34   1/1 = 2.29    Runway Outline (0/1) resulted in disproportionately
                           long response latencies, whereas its presence in
                           combination with a Runway Outline (1/1) resulted in
                           the shortest latencies.

Touchdown Zone x Texture
0/0 = 2.48   0/1 = 2.44    Presence of the Touchdown Zone in the absence of a
1/0 = 2.33   1/1 = 2.53    Texture Grid (1/0) resulted in disproportionately short
                           response latencies, whereas its presence in combination
                           with Texture Grid (1/1) resulted in slightly longer
                           latencies than with Texture Grid alone (0/1).

---

TABLE 10

Regression Equations, with their Associated Multiple Correlation Coefficients, for the Presence (1) or Absence (0) of the Various Display Elements at Near (N), Medium (M), and Far (F) Ranges from the Runway Aimpoint (underlined regression coefficients are statistically reliable; $p < .05$).

DISPLAY ELEMENT

| PREDICTED VALUE | Runway Outline $x_1$ | Touchdown Zone $x_2$ | Runway Centerline $x_3$ | Texture Grid $x_4$ | Glideslope Localizer $x_5$ | MULTIPLE CORRELATION |
|---|---|---|---|---|---|---|
| **Percent Correct Responses:** | | | | | | |
| $y_N =$ | $.000x_1$ | $+.039x_2$ | $+.\underline{165}x_3$ | $-.014x_4$ | $+.\underline{584}x_5$ | $\underline{R} = .632$ |
| $y_M =$ | $.\underline{117}x_1$ | $+.009x_2$ | $-.006x_3$ | $-.058x_4$ | $+.\underline{695}x_5$ | $\underline{R} = .707$ |
| $y_F =$ | $.\underline{185}x_1$ | $-.024x_2$ | $+.081x_3$ | $+.072x_4$ | $+.\underline{713}x_5$ | $\underline{R} = .745$ |
| **Median Latency, Correct Responses:** | | | | | | |
| $y_N =$ | $-.092x_1$ | $+.019x_2$ | $-.007x_3$ | $+.059x_4$ | $-.\underline{488}x_5$ | $\underline{R} = .546$ |
| $y_M =$ | $-.012x_1$ | $+.061x_2$ | $-.006x_3$ | $+.051x_4$ | $-.\underline{462}x_5$ | $\underline{R} = .500$ |
| $y_F =$ | $-.062x_1$ | $+.016x_2$ | $-.005x_3$ | $+.038x_4$ | $-.\underline{569}x_5$ | $\underline{R} = .608$ |
| **Median Latency, All Responses:** | | | | | | |
| $y_N =$ | $-.098x_1$ | $-.013x_2$ | $-.043x_3$ | $+.029x_4$ | $-.\underline{520}x_5$ | $\underline{R} = .582$ |
| $y_M =$ | $.000x_1$ | $+.056x_2$ | $+.021x_3$ | $+.079x_4$ | $-.\underline{499}x_5$ | $\underline{R} = .540$ |
| $y_F =$ | $-.039x_1$ | $+.000x_2$ | $-.002x_3$ | $+.056x_4$ | $-.\underline{620}x_5$ | $\underline{R} = .656$ |
| **Percent Incorrect Responses, Lateral Deviation:** | | | | | | |
| $y_N =$ | $-.\underline{191}x_1$ | $-.064x_2$ | $-.\underline{132}x_3$ | $-.064x_4$ | $-.\underline{293}x_5$ | $\underline{R} = .384$ |
| $y_M =$ | $-.\underline{148}x_1$ | $+.010x_2$ | $-.069x_3$ | $-.\underline{148}x_4$ | $-.\underline{465}x_5$ | $\underline{R} = .515$ |
| $y_F =$ | $-.\underline{235}x_1$ | $+.026x_2$ | $-.\underline{204}x_3$ | $-.108x_4$ | $-.\underline{390}x_5$ | $\underline{R} = .511$ |
| **Median Latency, Incorrect Lateral Responses:** | | | | | | |
| $y_N =$ | $-.072x_1$ | $-.090x_2$ | $-.\underline{155}x_3$ | $+.020x_4$ | $-.\underline{322}x_5$ | $\underline{R} = .386$ |
| $y_M =$ | $-.076x_1$ | $+.054x_2$ | $-.098x_3$ | $-.079x_4$ | $-.\underline{481}x_5$ | $\underline{R} = .509$ |
| $y_F =$ | $-.\underline{212}x_1$ | $+.048x_2$ | $-.097x_3$ | $-.041x_4$ | $-.\underline{414}x_5$ | $\underline{R} = .488$ |
| **Percent Incorrect Responses, Vertical Deviation:** | | | | | | |
| $y_N =$ | $.133x_1$ | $-.011x_2$ | $-.079x_3$ | $+.056x_4$ | $-.\underline{519}x_5$ | $\underline{R} = .567$ |
| $y_M =$ | $-.052x_1$ | $-.018x_2$ | $+.033x_3$ | $+.\underline{163}x_4$ | $-.\underline{574}x_5$ | $\underline{R} = .600$ |
| $y_F =$ | $-.057x_1$ | $-.025x_3$ | $+.083x_3$ | $+.000x_4$ | $-.\underline{621}x_5$ | $\underline{R} = .630$ |
| **Median Latency, Incorrect Vertical Responses:** | | | | | | |
| $y_N =$ | $.000x_1$ | $-.028x_2$ | $-.\underline{110}x_3$ | $-.020x_4$ | $-.\underline{457}x_5$ | $\underline{R} = .510$ |
| $y_M =$ | $.042x_1$ | $+.057x_2$ | $+.039x_3$ | $+.060x_4$ | $-.\underline{532}x_5$ | $\underline{R} = .568$ |
| $y_F =$ | $-.043x_1$ | $+.003x_2$ | $+.004x_3$ | $+.020x_4$ | $-.\underline{649}x_5$ | $\underline{R} = .654$ |

The findings from this study of final approach position judgments by flight instructors, in response to statically presented images of computer-generated skeletal "airport" scenes, can be summarized as follows:

1. The accuracy and speed of judgments are enhanced more by the presence of synthetic guidance information than they are by the perspective projections of any combination of four "contact analog" elements representative of the real-world visual scene on an approach to an airport. When the four T-bars that defined an imaginary Glideslope/Localizer beam (a "highway in the sky") were present, position judgments were rapid (less than 2 sec versus more than 3 sec, on average) and quite precise (in some conditions without error during 36 trials from various positions by each of eight pilots).

2. The relative contributions of the real-world cues varied as a function of range from runway aimpoint. Specifically, in the absence of the synthetic guidance symbols, judgments were consistently better when the contact analog elements included the Runway Outline, particularly at Far ranges from the touchdown aimpoint (which was always visible), whereas the presence of the Runway Centerline contributed more at Near ranges.

3. Neither the presence of Touchdown Zone markings (in addition to the ever present aimpoint) nor the surface Texture Grid

contributed reliably to the overall accuracy or speed
of judgments. In fact, the presence of the Texture Grid
was consistently accompanied by slower judgments, and at
Medium range it resulted in reliably more incorrect re-
sponses in the vertical dimension.

4. There were several statistically reliable first-order
interactions between visual elements as indicated in
Tables 4, 6, 8, and 9: most notably, the presence of
the Runway Outline contributed less when the Glideslope/
Localizer T-bars were present than when they were absent,
and the Texture Grid contributed favorably in the presence
of the Runway Outline whereas it interacted unfavorably
with the Touchdown Zone markers, and the latter resulted
in disproportionately slow responses in the absence of
the Runway Centerline.

# DISCUSSION

The generalizability of these findings is qualified by several factors. The pilots' judgments were made in response to the sudden appearance of static projections of skeletal visual scenes. The sudden appearance of the scene can be considered roughly analogous to breaking out of an overcast on a final instrument approach to a runway. The dynamics of movement toward the runway were not represented, and the scene disappeared immediately following the pilot's response with no indication of the correctness or incorrectness of the repsonse.

The superior performance associated with a synthetic perspective representation of an extended Glideslope/Localizer approach path illustrates the effectiveness of including specific guidance information, clearly encoded, relative to the perspective representation of real-world "contact analog" scenes. This is not to say that dynamic contact analog presentations alone do not contribute to spatial orientation, but it appears that such displays do not support the precise position and projected flight path discriminations required for all-weather instrument flight. The inclusion of guidance and/or prediction information in addition to the essential real-world elements in contact analog displays supports both rapid orientation and accurate control.

The linear regression equations presented in Table 10 account for a substantial proportion of the experimental variance observed but not for all of the variance that can be isolated. In view of the several reliable

interactions among some of the visual elements, revealed by the analyses of variance, regression equations that included the corresponding higher-order terms would similarly account for additional increments of variance and thereby yield higher multiple correlation coefficients. The values of these higher-order regression coefficients can be determined directly from the analyses of variance for dichotomous variables.

The use of a central-composite design, in conjunction with a conventional factorial combination of experimental display variables, served a somewhat different purpose from that for which CCDs are normally used. In this case, its purpose was to provide an efficient sampling of flight variables likely to affect the pilots' discrimination task, namely, three positional variables (lateral and vertical deviation from desired flight path and range from runway aimpoint) and two flight attitude variables (pitch and bank). Thus the task variables sampled in accordance with the CCD were not experimental variables in the usual sense, although they could be treated as such, and the data obtained could be submitted to overall regression analyses in which the dependent performance variables would be related to these continuous task variables as well as to the discrete display variables of primary interest.

The testing of pilots' responses to static presentations of computer-generated visual displays was a logical initial step in the screening of elements of real-world airport scenes that support judgments of flight attitude and position on final approaches to landing. The logical next step is the measurement of dynamic, closed-loop pilot performances in response to a relatively limited subset of the 12 displays studied

statically in this experiment. In fact, research currently in progress has already shown that the four essential contact analog elements — horison, runway outline, runway centerline, and landing aimpoint (or target) — do result in consistently accurate simulated landings by skilled pilots.

Furthermore, as would be predicted from the results of this experiment, the inclusion of synthetic guidance information, encoded in a form similar to that studied in this experiment, has a comparably beneficial effect upon dynamic, closed-loop landing performance. When presented and withdrawn automatically in accordance with an appropriate adaptive logic, the synthetic guidance cues also appear to facilitate the initial acquisition of landing skills and the subsequent transfer of those skills to situations in which synthetic guidance is not presented (Lintern, doctoral research in progress).

In view of the evident benefits of the integrated presentation of guidance information within true-perspective contact analog scenes, the possible interactive benefits of including dynamic flight-path prediction symbology in the same integrated display should also be investigated. An illustration of how flight-path prediction and a modified "highway in the sky" might be combined in a computer-generated contact analog is shown in Figure 6. If flight-path prediction is presented in this way, the resulting flight control task becomes one of pursuit rather than compensation. Pursuit displays, by definition, have at least two moving indices within a common reference system, one representing the pilot's own airplane or projected flight path and the other representing his desired position or flight path.
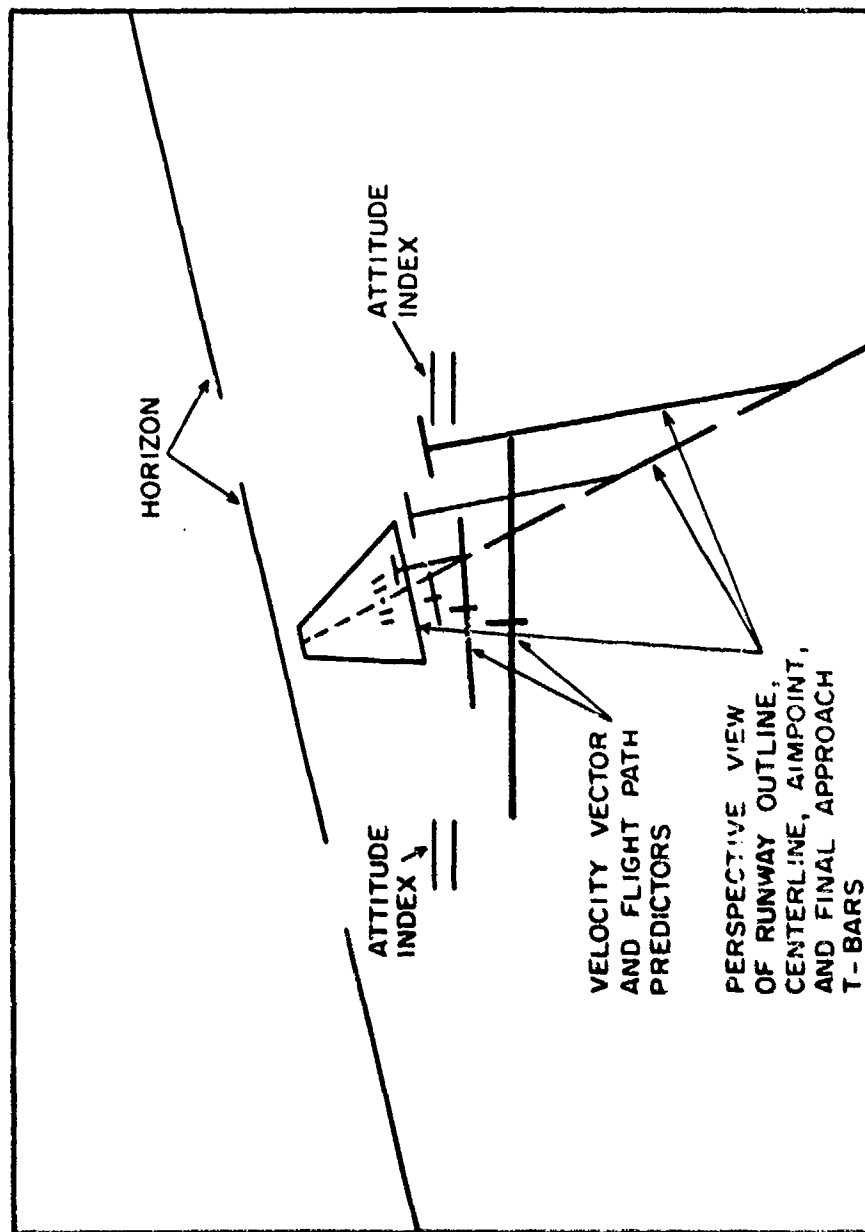
Figure 6. Integrated display of flight-path prediction, desired final approach path, and essential contact analog elements.

Any flight maneuver, including ones defined in relation to surface objects such as airport runways or ground targets, can be reduced to an abstract, error-nulling task with appropriate sensing, computing, and symbolic display devices. However, when the pilot's tracking task is reduced to that of a simple amplifier providing control inputs proportional to displayed error signals, his unique potential contributions can be lost, namely: resolving uncertainty, judging the reasonableness of the situation, and adjusting his indices of desired performance accordingly. It is by facilitating his intelligent action in the face of opportunity or adversity that pictorial situation displays of the type developed and tested in this program may contribute most directly to flight safety and mission success.

REFERENCES

Abbott, B. A. and Doughtery, D. J. Contact analog simulator evaluation; altitude and ground-speed judgments. Fort Worth, Texas: Bell Helicopter Company, Report D228-421-015, 1964. [AD 167-203]

Campbell, C. J., McEachern, L. J., and Marg, E. Flight by periscope. Wright-Patterson AFB, Ohio: WADC TR55-142, 1955.

Carel, W. L. Pictorial displays for flight. Culver City, Calif.: Hughes Aircraft Company, Report 273201/50, 1965. [AD 627-669]

Cochran, W. G. and Cox, G. M. Experimental designs (2nd ed.). New York: Wiley, 1957.

Cross, K. D. and Cavallero, F. R. Utility of vertical contact analog display for carrier landings: A diagnostic evaluation. Pt. Mugu, Calif.: Naval Missile Center, Report TP-71-52, JANAIR 201212, 1971.

Dougherty, D. J., Emery, J. H., and Curtin, J. G. Comparison of perceptual workload in flying standard instrumentation and the contact analog vertical display. Fort Worth, Texas: Bell Helicopter Company, Report D228-421-019, 1964. [AD610-617]

Edwards, A. L. Experimental design in psychological research. New York: Holt, Rinehart, and Winston, 1950.

Emery, J. H. and Dougherty, D. J.  Contact analog simulator evaluations: climbout, low cruise, and descent maneuvers.  Fort Worth, Texas: Bell Helicopter Company, Report D228-421-017, 1964.  [AD 603-744]

Ketchel, J. M. and Jenney, L. L.  Electronic and optically generated aircraft displays.  Arlington, VA.:  Matrix Corporation, Report JANAIR 680505, 1968.  [AD 684-849]

Kibort, B. R. and Drinkwater, F. J.  A flight study of manual blind landing performance using closed circuit television displays.  Moffett Field, Calif.:  Ames Research Center, Technical Note NASA TN D-2252, 1964.

Muller, C. G.  Numerical transformations in the analysis of experimental data.  Psychological Bulletin, 1949, 46, 198-223.

Myers, R. H.  Response surface methodology.  Boston:  Allyn and Bacon, 1971.

Roscoe, S. N., Hasler, S. G., and Dougherty, D. J.  Flight by periscope: Making takeoffs and landings; The influence of image magnification, practice, and various conditions of flight.  Human Factors, 1966, 8, 13-40 [Originally issued in 1952 as ONR Human Engineering Report SDC-71-16-9].

Williams, P. R. and Kronholm, M.  Technical report on simulation studies of an integrated electronic vertical display.  Norwalk, Conn.: Norden Division of United Aircraft Corporation, JANAIR Report 1161-R-0021, 1965.  [AD629-157]

Williges, R. C. Research note: Modified orthogonal central-composite designs. Human Factors, 1976, 18, 95-98.

Wulfeck, J. W. and Prosin, D. J., and Burger, W. J. Effect of a predictor display on carrier landing performance - Part I - Experimental evaluation (Part II - Laboratory mechanization, by L. E. Erhardt, F. R. Cavallero, and R. S. Kennedy). Inglewood, Calif.: Dunlap and Associates, Report NR 196-106, 1973.

Director, Engineering Psychology
Programs, Code 455
Office of Naval Research
800 North Quincy Street
Arlington, VA   22217   (5 cys)

Defense Documentation Center
Cameron Station
Alexandria, VA   22314   (12 cys)

Dr. Robert Young
Director, Cybernetics Technology Office
Advanced Research Projects Agency
1400 Wilson Blvd
Arlington, VA   22209

Lt. Col. Henry L. Taylor, USAF
OAD(E&LS) ODDR&E
Pentagon, Room 3D129
Washington, D.C.   20301

Office of Naval Research
International Programs
Code 102IP
800 North Quincy Street
Arlington, VA   22217   (6 cys)

Director of Technology
Code 200
Office of Naval Research
800 North Quincy Street
Arlington, VA   22217

Director, Electromagnetics
   Program, Code 221
Office of Naval Research
800 North Quincy Street
Arlington, VA   22217

Commanding Officer
ONR Branch Office
ATTN: Dr. J. Lester
495 Summer Street
Boston, MA   02210

Commanding Officer
ONR Branch Office
ATTN:  Dr. Charles Davis
536 South Clark Street
Chicago, IL  60605

Commanding Officer
ONR Branch Office
ATTN:  Mr. R. Lawson
1030 East Green Street
Pasadena, CA  91106

Dr. M. Bertin
Office of Naval Research
Scientific Liaison Group
American Embassy, Room A-407
APO San Francisco  96503

Director, Naval Research Laboratory
Technical Information Division
Code 2627
Washington, D. C.   20375   (6 cys)

Mr. John Hill
Naval Research Laboratory
Code 5707.40
Washington, D. C.   20375

Office of the Chief of Naval
   Operations, OP987P10
Personnel Logistics Plans
Department of the Navy
Washington, D. C.   20350

Mr. Arnold Rubinstein
Naval Material Command
NAVMAT 0344
Department of the Navy
Washington, D. C.   20360

Commander
Naval Air Systems Command
Human Factors Programs, AIR 340F
Washington, D. C.   20361

Commander
Naval Air Systems Command
Crew Station Design, AIR 5313
Washington, D. C.   20361

Mr. T. Momiyama
Naval Air Systems Command
Advance Concepts Division, AIR 03P34
Washington, D. C.   20361

Mr. George Tsaparas  
Naval Air Systems Command, AIR 340  
Washington, D.C.   20360  

LCDR R. Gibson  
Bureau of Medicine & Surgery  
Aerospace Psychology Branch  
Code 513  
Washington, D.C.   20372  

Dr. George Moeller  
Human Factors Engineering Branch  
Submarine Medical Research Laboratory  
Naval Submarine Base  
Groton, CT   06340  

Chief, Aerospace Psychology Division  
Naval Aerospace Medical Institute  
Pensacola, FL   32512  

Dr. Lloyd Hitchcock  
Human Factors Engineering Department  
Crew Systems Division  
Naval Air Development Center  
Warminster, PA   18974  

Bureau of Naval Personnel  
Special Assistant for Research  
    Liaison  
PERS-OR  
Washington, D.C.   20370  

Dr. Fred Muckler  
Navy Personnel Research and  
    Development Center  
Manned Systems Design, Code 311  
San Diego, CA   92152  

CDR Charles Theisen  
Human Factors Engineering Branch  
Crew Systems Department  
Naval Air Development Center  
Johnsville  
Warminster, PA   18974  

LCDR William Moroney  
Human Factors Engineering Branch  
Code 1226  
Pacific Missile Test Center  
Point Mugu, CA   93042  

Mr. Ronald A. Erickson  
Human Factors Branch  
Code 3175  
Naval Weapons Center  
China Lake, CA   93555  

Human Factors Section  
Systems Engineering Test Directorate  
U. S. Naval Air Test Center  
Patuxent River, MD   20670  

Naval Training Equipment Center  
ATTN:   Technical Library  
Orlando, FL   32813  

Human Factors Department  
Code N215  
Naval Training Equipment Center  
Orlando, FL   32813  

Dr. Gary Poock  
Operations Research Department  
Naval Postgraduate School  
Monterey, CA   93940  

Dr. A. L. Slafkosky  
Scientific Advisor  
Commandant of the Marine Corps  
Code RL-1  
Washington, D.C.   20380  

Mr. J. Barber  
Headquarters, Department of the  
    Army, DAPE-PBR  
Washington, D.C.   20546  

Technical Director  
U.S. Army Human Engineering Labs  
Aberdeen Proving Ground  
Aberdeen, MD   21005  

U.S. Air Force Office of Scientific  
    Research  
Life Sciences Directorate, NL  
Bolling Air Force Base  
Washington, D.C.   20332  

Lt. Col. Joseph A. Birt  
Human Engineering Division  
Aerospace Medical Research Laboratory  
Wright Patterson AFB, OH   45433

Dr. W. S. Vaughan
Oceanautics, Inc.
422 6th St.
Annapolis, MD 21403

Dr. Alphonse Chapanis
The Johns Hopkins University
Department of Psychology
Charles & 34th Streets
Baltimore, MD 21218

Dr. Robert R. Mackie
Human Factors Research, Inc.
Santa Barbara Research Park
6780 Cortona Drive
Goleta, CA 93017

Dr. Gershon Weltman
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. Edward Jones
McDonnell-Douglas Astronautics
    Company-EAST
St. Louis, MO 63166

Dr. J. W. Wulfeck
New Mexico State University
Department of Psychology
Box 5095
Las Cruces, NM 88003

Dr. H. Rudy Ramsey
Science Applications, Inc.
40 Denver Technological Center West
7935 East Prentice Avenue
Englewood, Colorado 80110

Dr. Ross L. Pepper
Naval Undersea Center
Hawaii Laboratory
P.O. Box 997
Kailua, Hawaii 96734

Dr. Robert G. Pachella
University of Michigan
Department of Psychology
Human Performance Center
330 Packard Road
Ann Arbor, MI 48104

Dr. Robert Fox
Vanderbilt University
Department of Psychology
Nashville, TN 37240

Dr. Jesse Orlansky
Institute for Defense Analysis
400 Army-Navy Drive
Arlington, VA 22202

Dr. Stanley Deutsch
Office of Life Sciences
HOS, NASA
600 Independence Avenue
Washington, D.C. 20546

Director, Human Factors Wing
Defense & Civil Institute of
    Environmental Medicine
Post Office Box 2000
Downsville, Toronto, Ontario
CANADA

Dr. A. D. Baddeley
Director, Applied Psychology Unit
Medical Research Council
15 Chaucer Road
Cambridge, CB2 2EF
ENGLAND

Dr. David Zaidel
Road Safety Centre Technion City
Haifa
ISRAEL